Environmental externalities and their effect on the cost of consumer products

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Abstract: Economic activities generate pollution, which causes damages to the society and the environment. It is possible to estimate the quantities of emitted pollutants from energy conversion systems using thermodynamic principles combined with empirical techniques. The indices of direct emission are often not sufficient to show the entire environmental load because production processes are interconnected. The methodology of determination of cumulative exergy consumption was proposed by Szargut as the thermo-ecological cost (TEC). Recently, Szargut and Stanek published the methodology of cumulative CO_2 emission determination called thermo-climatic cost (TCC). The main objective is to show that the TCC can be extended to evaluation of emission of any harmful substance. To achieve that, the new index of cumulative emission (CEm) is proposed. Two different methods of evaluating the cost of emission are presented; physical (exergy) used to investigate the influence of emission on the depletion of natural resources; and economic (monetary) used to show the influence of externalities on the market prices of consumer goods.

Keywords: thermo-ecological cost; TEC; cumulative emissions; exergy cost; environmental externalities; society damages; environmental damages; harmful substances; natural resources depletion; emission evaluation; thermo-climatic cost; TCC.

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1 Introduction

Our present civilisation is based mainly on the non-renewable resources of fuels and minerals. The depletion of natural non-renewable resources is accelerated by an increasing consumption level of society. From the economic point of view the increase of consumption level is the base for further development and is one of the indicators of human development. However, the impact of the consumption sector can provide an ecological threat to the existence of future generations. As long as society are unable to conclude that can cover their needs only from renewable resources or alternative energy such as nuclear energy, so long they must take into account the serious threat of depletion of non-renewable natural resources. From the perspective of sustainable development increasing consumption, in particular unbridled consumption is unfavourable. Uncontrollable consumption, in contrast to economic approach, should be reduced.

Environmental risks associated with the growth of consumption can be divided into two groups:

- depletion of non-renewable natural resources
- harmful waste products discharge into the environment.

Damage caused by the second type of interactions can also be expressed through its effect on depletion of non-renewable natural resources, since losses arising in the environment resulting from discharge of harmful waste products should be compensated or prevented. In order to achieve this goal, the use of renewable resources should be increased. Prevention of environmental damage resulting from emission also entails some economic investments. These expenditures through a network of interrelationships of production processes are always transferred to the recipient of the finished products. To determine the load, not only direct emissions and its local cost occurring in the system, but their accumulation and transfer to the final product should be taken into account. Therefore, such an analysis should be based on cumulative calculus. The calculation of the cumulative coefficients has been initiated by Chapman, who introduced the concept of energy cost (Chapman, 1974). The theory of energy cost of useful products has been developed by Boustead and Hancock (1979). Szargut introduced the concept of cumulative exergy consumption (CExC) (Stanek, 2009) and then the thermo-ecological cost (TEC) expressing the cumulative consumption of non-renewable exergy (Szargut, 1999). The later method provides a comprehensive tool to assess the impact of production processes on the depletion of non-renewable natural resources. It should be strongly emphasised that, the Szargut's method in comparison with other methods of ecological assessment, can bring all impacts to one measure which is exergy.

The minimisation of the TEC (Stanek, 2001; Szargut and Ziębik, 2000; CSOP, 2010) ensures a mitigation of the depletion of non-renewable resources. Actually, the problem of many emissions becomes more important, because the climatic damages will presumably appear in a near future. Therefore, in some applications, only cumulative emissions are on the main interest. For this purpose, Szargut proposed adaptation of algorithm of calculating the thermoecological cost for calculation the cumulative CO_2 emissions (TCC) (Szargut and Ziębik, 2000; Szargut, 2007). This algorithm and the results of sample analysis were published by Szargut and Stanek (Szargut and Ziębik, 2000).

The TCC of the domestic consumption products expresses the cumulative emission burdening all the stages of production processes connected with the fabrication of particular products. The primary source of the CO_2 emission is the combustion of hydrocarbon fuels such as hard coal, lignite, natural gas and liquid fuels produced from crude oil. Additionally, the primary sources of SO_2, NO_X and PM are generally the same as in case of CO_2 emission. These pollutants arise in electricity production process and industrial process, however electricity is one of the most important part of every other industrial and non-industrial process, and these emission burden nearly all other activities.

The authors of this article suggest extending the cumulative CO_2 calculus to other harmful substances, in particular to SO_2, NO_X, PM. Since the harmful effects of each of these substance is could lead to important external effects of energy transformation and other economic processes.

The proposed algorithm for tracking the process of emissions cumulation can also be easily adapted to the track formation process of economic cost resulting from pollution cumulating itself among the combined production branches. In other words this cost expresses the consumer goods burdening by the main results from the environmental costs. Such an account can be particularly important for tracking the cumulation of costs resulting from greenhouse gases, including CO_2 emissions as well as other effluence. The direct costs of losses due to the discharge of aggressive products into the environment, so called *externalities*, should be introduced into the equations in order to adapt the TCC algorithm to the CEm. Determination of economic losses and additional expenses resulting from natural resources from the need of prevent environmental loss is a difficult task. Often in these analyses, losses are estimated on the basis of the so-called fees for discharges of harmful substances. These fees often have no direct correlation with losses because their values derive from the administrative findings. In Poland, according the current regulation, fee for CO_2 emissions of CO_2 is 0.26 PLN/ton (Dz.U. 2005 nr 260 poz. 2181), while in the EU fee is expected within the interval 15–60€/ton or up to 100€/ton (Jakubowicz, 2010) as a level of economic profitability of CO_2 capture and storage (CCS).

An additional difficulty is that the emission of pollutants from energy conversion systems causes damages to the environment and the society not only in the vicinity of the system but also in distant areas, even in other countries, that are in the trajectory of pollutants dispersion. For this reason it is necessary to identify these damages in every place where they appear, not only in energy sectors, but also for other production sectors with inclusion of effects of dispersion of pollutants. The cumulative emissions, which are the sum of emission that burden every stage of production of selected product or activity are burdened with economic costs of losses using results of tools as EcoSenseWeb software and GAINS application.

The term ‘externalities’ is widely used to express the costs of damages to the environment and the society (Bickel and Friedrich, 2005; Krewitt et al., 1995; Schleisner, 2000). Nowadays, external costs resulting from certain damages are not reflected in the market prices of the products, but governments (hence also the industry) start taking these costs into consideration in management decisions as a result of national and European laws.

The EcoSenseWeb Software based on the ExernE project and developed by Krewitt's team (Bickel and Friedrich, 2005; Krewitt et al., 1995) has been used, which applies the Impact Pathway Approach (IPA), in order to estimate the environmental damages resulting from airborne pollutants

The objective of this work is to assess the cost of pollution using different methods. First of all the authors explained the methodology of cumulative emission evaluation. Than proposal of physical costing (exergy) and economic costing (in monetary units) of these emission factors are explicated. For the purpose of economic costing the EcoSenseWeb (Krewitt et al., 1995; Preiss and Klotz, 2007) and GAINS (Amann et al., 2008; Cofała et al., 2009) software are used. EcoSenseWeb is based on the results of the ExternE (Bickel and Friedrich, 2005; ES, 2008) project, whereas GAINS is developed at the International Institute for Applied Systems Analysis and takes into account air pollution policies. The procedure for estimating the cost of externalities is described. For the purpose of physical costing of cumulative emissions – the thermoecological cost is proposed. The proposed and developed methodology is supported with practical example illustrating the influence of cumulative externalities on final cost of selected consumption goods.

2 Externalities and environmental cost

Harmful substances including emissions could be divided into two groups. The first group contains substances such as sulphur dioxides, nitric oxide and particulate matters (PMs), which affect in adverse manner on surrounding environment. The second group includes greenhouse gasses, which are also emitted especially from fuels conversion processes. However, it is not proved that they influence in adverse way to the environment in the sense of direct losses in human health, buildings, forestry etc.; however, they can be responsible for future global warming.

Nowadays, full external costs resulting from certain damages are not reflected in the market prices of the products, but governments (hence also the industry) start taking these costs into consideration in management decisions as a result of national and European laws (GAINS 2009; Dz.U. 2005 nr 260 poz. 2181).

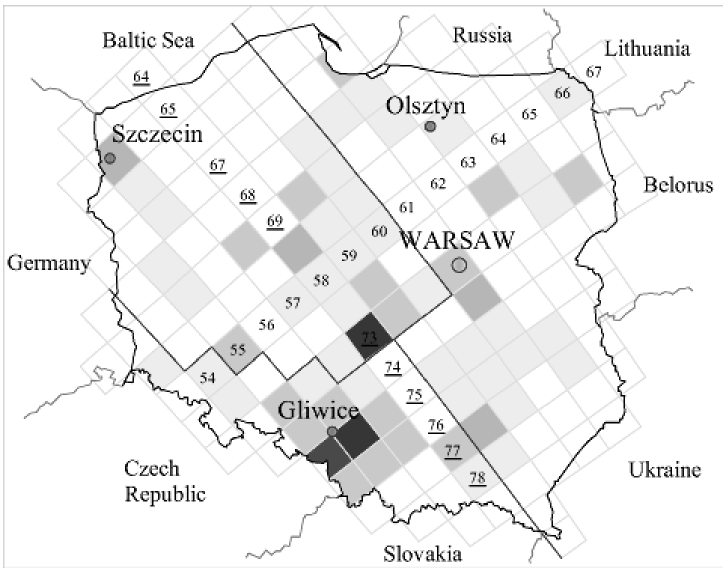
The externalities of pollutants from industrial activities depend primarily on the location of this activity. The same amount and types of the emissions of harmful pollutants give different effects at different locations, because the adverse effects on the society and the environment are strongly related with population density, site-specific meteorological data, infrastructure, etc. The EcoSenseWeb (Krewitt et al., 1995; Preiss and Klotz, 2007) software has been developed for the assessment of impacts on the environment and the society from industrial activities, and for the estimation of the external costs due to these impacts. The assessment of impacts is based on the IPA developed in the ExternE (externalities of energy) project (Bickel and Friedrich, 2005; Krewitt et al., 1995), funded by the European Commission, and it provides data for an integrated impact assessment associated with pollutants.

The IPA starts with the quantities of various pollutants emitted at a certain location in one of sub-regions in Europe or six regions outside Europe. In the second step, using the atmospheric pollutant transport module, which takes into account wind speed and direction, baseline (current) concentrations of pollutants and chemical transformation of pollutants, the marginal changes in the ambient conditions are modelled. The third step consists of the impact assessment of damages such as impacts on health, building materials, crops and land, due to harmful pollutants. For this purpose, the dose-response function is used, which relates the quantity of pollutants with the physical effect on the receptors, e.g. number of hospitalisations. Then, the results from the three steps are aggregated and converted to monetary values, in order to obtain the external cost.

Using present state of knowledge regarding to the effect of harmful substances emitted into the environment, the greatest impact is on human health. Externalities obtained for sources located in Olsztyn are related to human health (91.37%), crops (1.07%), buildings material (3.44%) and biodiversity losses due to acidification and eutrophication (4.12%) (Czarnowska and Frangopoulos, 2009).

The externalities were calculated (Czarnowska and Frangopoulos, 2010) for the four Polish cities, which have the following coordinates: Gliwice (18º33'E, 50º21'N); Szczecin (14º42'E, 53º26'N), Olsztyn (20º27'E, 53º47'N) and Warsaw (21°3'E, 52°11'N), these cities are located in three different sub-regions of Poland (Figure 1). The details of modelling of externalities were presented in Czarnowska and Frangopoulos (2009, 2010). The results from EcoSenseWeb Software depend on background of emission, which is related to real concentration of pollutants and it is presented using grid in sub-region of Europe. Figure 1 shows a 50 × 50 km^2 grid of Poland, three sub-regions in Poland and selected cities.

Figure 1 50×50 km^2 grid of Poland with the highest concentration of pollutants in background and cities selected for calculation



The disused above externalities can be classified as economic one. Moreover, the physical-exergetic assessment of external costs of can be carried out. In the case of exergetic evaluation the following costs can be distinguished:

- TEC of emission (Stanek, 2001):

$$\zeta_k = \frac{B w_k}{GDP + \sum_k P_k w_k} \tag{1}$$

where

B	exergy of the domestic non-renewable natural resources extracted per year
GDP	gross domestic product
P_k	annual production of the k^{th} aggressive component of waste product rejected to the environment in the considered region
w_k	monetary factor of harmfulness of k^{th} substances (discussed in the next section).

- Abatement cost of emission (Stanek, 2001):

$$\sigma_k = \frac{\sum_j G_{jk}\,\rho_j - \sum_u G_{uk} s_{iu} \rho_i}{G_k} \tag{2}$$

where

G_{jk}	number of j^{th} raw material, semi-finished product or energy carrier used in conjunction with removal of the k^{th} pollutant
G_k	amount of the k^{th} removed pollutant
G_{uk}	amount of the u^{th} by-product in removal process of the k^{th} pollutant
ρ_j, ρ_i	thermoecological cost j^{th} and i^{th} product
s_{iu}	replacement ratio of the i^{th} product with u^{th} by-product.

Table 1 shows, the average external cost of each pollutant w_k obtained by EcoSenceWeb Software, ratio ζ_k as exergetic cost of compensation environmental losses due to these pollutants, monetary cost c_k and abatement cost σ_k. In order to calculate ζ_k, ratio was used exergy of resourced used during year B = 2959 PJ/(year$_{2008}$) assessed on the basis of (Czarnowska and Frangopoulos, 2009; CSOP, 2010) and GDP = 363.8 mld €$_{2008}$ in current price (Eurostat).

Table 1 Monetary cost of emission (Czarnowska and Frangopoulos, 2009, 2010; Dz.U. 2005 nr 260 poz. 2181) and thermoecological cost of emission (Stanek, 2009)

No.	*Indicator*	*Units*	*Substance*			
			SO_2	*NO_x*	*PM*	*CO_2*
1	c_k	€ emission/kg emission	0.12	0.12	0.08	0.015
2	w_k	€ externalities/kg emission	12.81	9.41	7.00	-
3	ζ_k	MJ_{ex}/kg	97.82	71.88	53.42	-
4	σ_k	MJ_{ex}/kg	17.5	26	0.5	4.4

From Table 1, it can be easily lead that:

- external with expressing the real environmental loses are much higher than the present administrative fee for rejection of waste to the environment, for this reason it is interesting to check how the cummulation of external costs would influence the prices of the final products.
- ratio ζ_k are lower then abetment cost σ_k which mean that in all considered cases the abatement is advantageous from the point of view of non-renewable resources savings.

3 The algorithm for calculations of cumulative emissions and cumulative externalities

Model for the calculation of cumulative emissions (NO_X, SO_2, PM), and CO_2 is based on an algorithm presented by Szargut and Stanek (Szargut and Zięebik, 2010). The algorithm presented in Szargut and Zięebik (2000) has been originally developed for the evaluation only of the cumulative emission of CO_2 (TCC). However, it can be easily extended to other effluence. In this paper the authors show the adaptation of TEC algorithm for evaluation of cumulative emission of any harmful substance. The general form balance equation determining the cumulative emissions of waste products released to the environment during production of final consumption products is based on the same principles as in the case of calculation of the cumulative exergy consumption (CExC) (Szargut, 1999, 2005) or in the case of TEC (Stanek, 2009; CSOP, 2010). The cumulative balance of considered k^{th} harmful substance burdening fabrication of j^{th} consumption product takes the following form

$$\varepsilon_j + \sum_i \left(f_{ij} - a_{ij} \right) \left[\beta_i \varepsilon_i + \left(1 - \beta_i \right) \varepsilon_{iim} \right] = \sum_k e_{kj} \tag{3}$$

where

a_{ij}, f_{ij} coefficient of consumption or by-production of the i^{th} semi-finished product, per unit of the j^{th} major product

β_i share of domestic production in the balance of consumption of i^{th} product

ε_i, ε_j cumulative emission of considered waste per unit of i^{th} and j^{th} consumption good

ε_{kj} rate of direct emission of considered waste resulting from consumption of k^{th} good in j^{th} production branch.

In the case of emissions of CO_2 the last part of equation (3) can be expressed using the total TCC burdening the utilisation of k^{th} fuel. In such case the balance equations takes the following form:

$$\varepsilon_j + \sum_i \left(f_{ij} - a_{ij} \right) \left[\beta_i \varepsilon_i + \left(1 - \beta_i \right) \varepsilon_{i\mathrm{im}} \right] = \sum_k a_{kj} \varepsilon_k \tag{4}$$

where a_{kj} denotes coefficient of consumption of the k^{th} fuel, per unit of the j^{th} major product.

The total TCC of k^{th} fuel appearing in equation (4) of cumulative CO2 emission should include primary TCC of the k^{th} fuel, resulting from the combustion of C and the

TCC of the delivery and processing of k^{th} fuel. Because in the domestic economy part of fuels are coming from import (natural gas and crude oil), the inclusion of the TCC of imported fuels in the equation (4) is necessary. Therefore, the total TCC of *k*-the fuel can be described by the following equations:

$$\varepsilon_k = (1 + a_k)\varepsilon_{Fk} + (1 - \beta_k)\varepsilon_{k\,\mathrm{im}} \tag{5}$$

where:

ε_{Fj} primary TCC of the k^{th} fuel, resulting from the combustion

α_k coefficient of delivery and processing of the k^{th} fuel

β_k domestic fraction in the total consumption of k^{th} fuel

$\varepsilon_{k\mathrm{im}}$ TCC of k^{th} imported fuel.

The values of the primary TCC are cited in Table 2. The value ε_F is the higher, the larger the ratio of carbon content to the hydrogen content in the combustible component of fuel. The content of oxygen in the combustible component increases also the value of ε_F.

The TCC of delivery and processing $\varepsilon_{\mathrm{pr}} = a\varepsilon_F$ is resulting from the consumption of chemical energy for the extraction from domestic natural deposits, processing and transportation (in the case of solid fuels and natural gas) and for the production of liquid fuels from crude oil.

Table 2 The primary as well as delivery and processing TCC of fuel coefficient

Fuel type	ε_F	α_k
Hard coal	0.0940	0.07
Lignite	0.0120	0.09
Coke	0.0990	0.31
Natural gas	0.0532	0.02
Motor oil	0.0793	0.17
Gasoline	0.0727	0.24
Natural gas (domestic)	0.0640	0.24

Source: Szargut and Stanek (2010)

The values of the domestic fraction of in the consumption of fuels in the year 2008, are cited in Table 3, according to (CSOP, 2010). A small fraction of the imported hard coal in the domestic consumption has been also taken into account. In the case of crude oil in Polish conditions almost 100 % are imported from abroad.

Table 3 Domestic fraction of total fuel consumption in year 2008

Fuel	*Domestic fraction in the consumption*
Natural gas	36%
Crude oil	1%
Hard coal	90%
LPG	11%

Source: CSOP (2010)

Application of the equation (3) to equation (5) requires the knowledge on the cumulative emissions burdening the imported fuels and imported useful consumer products. To solve this problem it has been assumed (Stanek, 2001; CSOP, 2010) that the financial means for the import of fuel are gained by export of the domestic products burdened by TCC. It can be assumed, that the value of TCC per unit of the monetary unit is the same for the exported as for the imported products. The algorithm of evaluation of imported goods is presented in details in Stanek (2001), Szargut (1987a, 1987b) and Szargut (1999).

Based on the results of calculations of cumulative emission index of considered waste product burdening the fabrication of j^{th} useful good ε_j, the cumulative external cost can be determined. Algorithm of determination of the cumulative emission burdening the elements of productive system described by equation (3) to equation (5) can be extended for purposes of costing of these emissions. When we introduce the generalised cost λ_k in relation to the unity of emission the costing formula for total cost of considered emission burdening j^{th} can be derived in the form:

$$k_{tot,j} = \varepsilon_j \lambda_k \tag{6}$$

The values of physical and economical assessment of the generalised cost λ_k are summarised in Table 4.

Table 4 Pollutants costing options

No.	λ_k	*Scenario*	*References*
Physical cost, in natural units			
1	$\lambda_k = 1$	Cost allocation is done in natural units using the quantities of substances.	
Economic cost, in monetary units			
2	$\lambda_k = c_k$	Cost allocation is done in monetary units using fees for use of the environment.	Dz.U. 2005 nr 260 poz. 2181
3	$\lambda_k = w_k$	Cost allocation is done in monetary units resulting from the estimation of economic losses caused by the discharge of harmful substances into the environment.	Czarnowska and Frangopoulos (2009, 2010)
Exergetic cost, in relation to the cumulative consumption resources			
4	$\lambda_k = \zeta_k$	Cost allocation is done in exergy units resulting from depletion of non-renewable natural resources required to compensate.	Czarnowska and Frangopoulos (2009), Stanek (2001) and CSOP (2010)
5	$\lambda_k = \sigma_k$	Cost allocation is done in exergy units resulting from depletion of non-renewable natural resources required to prevention.	Stanek (2001)

4 Results of sample calculations

The example shows the determination of cumulative indicators of emissions for the energy and selected consumer goods. Calculations based on the balance method of determining cumulative indices, which is described in paragraph 3 in presented paper.

The direct emission of CO_2 ε_F burdening the combustion of fuel, results from the simple stoichiometric formula:

$$\varepsilon_F = \frac{44}{12}\frac{c}{H_L}\left[\frac{kg\,CO_2}{MJ}\right] \quad (7)$$

where

c carbon content in the fuel unit, kg/kg, kg/kmol

H_L lower heating value of the fuel, MJ/kg, MJ/kmol.

In case of CO_2 emission the larger the ratio of carbon contents in fuel, the higher the value of primary TCC ε_F. SO_2, NO_x and PM emissions is assumed for each activity according to GAINS. Unit emissions of waste products burdening the unit of chemical energy of primary fuels are shown in Table 5.

Table 5 The primary TCC of air pollution aggregated by fuel type

k no.	*Emission*	*CO_2*[1]	*SO_2*[2]	*NO_X*[2]	*PM TSP*[2]
	Fuel type	*kg of emission / GJ of energy*			
1	Hard coal	94.0	0.2020	0.0736	0.0366
2	Brown coal/lignite	120.0	0.0859	0.0691	0.0070
3	Derived coal (coke. briquettes)	99.0	0.0746	0.0352	0.0124
4	Natural gas (incl. other gases)	53.2	-	0.0443	0.0001
5	Heavy fuel oil	79.3	0.0994	0.0520	0.0052
6	Gasoline and other light fractions of oil	72.7	0.0007	0.1721	0.0051

Notes: [1]Calculated by equation (6)
[2]Average assessment of emission (Amann et al., 2008; Cofała et al., 2009; GAINS, 2010)

The results of the calculation of cumulative emissions and its economic evaluation are shown:

- for fuel usage in national economy in Table 5
- for useful selected goods in Table 6.

Table 6 Cumulative emissions (CEm) burdening domestic fuels and share of externalities in fuel price

Fuel	*Emission*				*External cost*			
	SO_2	*NO_X*	*PM*	*CO_2*	*SO_2*	*NO_X*	*PM*	*CO_2*
	kg emission/GJ fuel				*€ externalities / € fuel*			
Hard coal	0.22	0.08	0.04	101.78	1.6683	0.4650	0.1795	0.8980
Natural gas	0.08	0.13	0.07	72.43	0.1159	0.1326	0.0522	0.1207
Lignite	0.09	0.08	0.01	130.80	2.2204	1.3104	0.0972	3.6333
Coke	0.10	0.05	0.02	129.69	0.1097	0.0381	0.0099	0.1706
Motor oil	0.02	0.55	0.04	94.90	0.0095	0.1857	0.0096	0.0508
Gasoline	0.02	0.23	0.02	94.39	0.0127	0.1093	0.0077	0.0708

Table 7 Cumulative emissions (CEm) burdening domestic goods and share of externalities in goods price

Fuel/ semi-finished products/finished products	*Emission*				*Share of external cost*			
	SO_2	NO_X	*PM*	CO_2	SO_2	NO_X	*PM*	CO_2
	kg emission/ton product				*€ externalities/€ product*			
Steel blocks	55.56	54.69	53.85	2,670	0.7085	0.5123	0.3752	0.0399
Cooper	64.82	97.16	51.29	57,886	0.1759	0.1937	0.0761	0.1839
Steel products	44.13	43.47	42.93	1,928	1.4146	1.0236	0.7520	0.0724
Aluminum	48.89	18.55	9.62	22,473	0.2047	0.0571	0.0220	0.1102
Machines and devices	5.80	4.90	4.36	1,020	0.0101	0.0062	0.0041	0.0021
Agricultural products – meat	2.43	7.68	0.91	2,218	0.0161	0.0373	0.0033	0.0172
Agricultural products – vegetable	0.98	3.11	0.37	894	0.0140	0.0328	0.0029	0.0150
Paper	6.32	2.40	1.24	2,905	0.1033	0.0288	0.0111	0.0556
Fertiliser	4.45	6.93	3.67	3,957	0.1806	0.2066	0.0814	0.1881
Silver	5.26	49.30	4.02	9,829	0.0002	0.0014	0.0001	0.0004
Rubber products	7.81	2.97	1.54	3,592	0.0622	0.0174	0.0067	0.0335
Glass	1.99	7.14	1.29	2,135	0.0274	0.0721	0.0097	0.0343
Wood	2.36	0.89	0.46	1,083	0.0962	0.0268	0.0103	0.0518
Sulphur	1.07	0.41	0.21	494	0.0658	0.0183	0.0071	0.0354
Cement	1.10	0.44	0.23	514	0.1529	0.0449	0.0174	0.0836
Electricity	0.62	0.24	0.12	285	0.1786	0.0508	0.0189	0.0962

The proposed modification of TEC algorithm primary developed by Szargut let us to investigate the problems described above for the case of CO_2 to other harmful wastes. In this paper, the analysis concerns SO_2, NO_x, PM.

From the presented results, based on developed algorithm several interesting conclusions can be drowning. First of all, in case of fuels, the most cumulative CO_2 emissions TCC burden the use of carbon fuels, in particular, the coke and lignite. Coke should not be used for energy purposes, as it can be replaced by much better fuels from viewpoint of TCC, e.g. by coal. Natural gas is characterised by definitely the most preferred indicator TCC. Gasoline is much worse than natural gas and only a little bit better than hard coal.

The monetary assessment of cumulative CO_2 emission shows that the cumulative external price could lead to the significant increase of the price of fuel and then of other consumer products. The extreme situation is observed in the case of lignite. In this case the price of cumulative CO_2 emission is approximately three times higher than the price of lignite. The presented numbers indicate that in the face of observed more effort to climate change related topic the profitability of coal and lignite fired power plants would become no justified.

The estimated share of external costs resulting from the cumulative emissions burden the fuel is especially clear for SO_2 in the case of solid fuels (coal and lignite). It is resulting from the relatively high-sulphur; however in case of lignite it is due to relatively low calorific value.

Also, for cumulative NO_x emissions and their impact on the externalities involved in the fuel cost the worst case is solid fuels, 50% for coal and 130% for lignite.

For useful products that are partially affected by fuel externalities, the share of externalities in the total price of products would be:

- for SO_2 the lowest value is in the case of silver 0.2%, and the highest value is in the case of aluminium 141%
- for NO_x the lowest value is in the case of silver 0.1%, and the highest value is in the case of steel products 100%
- for PM, it is similar to NO_X, the lowest value is in the case of silver 0.1%, and the highest value is in the case of steel products 75%
- for CO_2, the lowest value is in the case of machines and devices 0.1%, and the highest value is in the case of fertiliser 75%.

The presented results prove that taken into account externalities based on the cumulative calculus for certain goods would have a decidedly negative impact on level of fuel prices. On the other hand, the introduction of fees proposed in the presented indicators lead the consumption towards sustainable development.

The presented example results focused only on costing of the cumulative emission by means of monetary evaluation of external environmental costs. But it is also possible the physical costing (see Table 4). In this case the factors of emissions included in Table 6 and Table 7 should be multiplied due to equation (6) by the generalised cost equal to abatement cost $\lambda_k = \sigma_k$ or equal to thermoecological cost $\lambda_k = \zeta_k$.

5 Conclusions

The results and the discussion presented in this paper represent a confirmation that an unreasonable manipulation of the rules for determining the costs for emissions may have serious consequences when it comes to the final price of the goods. The impact is in one direction - increasing prices of goods. This trend is reflected on the end-users (households) or in the intermediate cells. The paper shows that it is possible based on the laws of physics to determine the effect of externalities on prices of final consumer goods. In the face of the existence of such tools, the authors postulate that the issue price of waste products should not be solely the result of speculators often administrative arrangements.

Because the applied specific costs of emissions could have a significant influence on the final product, their level should be assumed with reasonable diligence. High charges for external costs significantly could inhibit consumption of useful products. It would be undesirable from an economic point of view. However, the introduction of appropriate environmental taxes proportionate to the proposed indicators certainly eliminates the unreasonable consumption of products especially harmful emission into the environment.

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